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The overall goal of this project is to adapt tapered monolithic optics to a real clinical mammography unit at the Radiology department, University of Wisconsin. Fourteen tapered optics were mounted into a multiple optic unit to affect larger area. Individual optics were characterized for transmission, uniformity, magnification factor, and magnification uniformity with a mammography unit and a digital detector. Although the mounted array did not show a good performance because of the poor alignment design, individual optics showed an average of 73 % transmission with good uniformity and a magnification factor of 1.6.

The PI also participated in an approved medical physics program at the University of Wisconsin where she took classes and participated in quality assurance clinical training. Therefore, she can be eligible for taking her board certification in diagnostic radiology when she finishes her post-doctoral training.

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Introduction

Mammography has been proven to be the most effective way to detect early stages of tumors in breasts. An improvement in mammography may greatly diminish false readings. By inserting a tapered monolithic optic between the patient and the detector, scattered radiation can be eliminated which improves the image on the detector. A detailed investigation of this optic is needed for mating it with a digital detector. Although in the statement of work, it shows that the initial optic investigation would be done in University at Albany, with later work proceeding at the University of Wisconsin, the PI began work at UW. At UW, she had the opportunity to use an actual mammography source, which was not available in Albany.

In addition, at UW, the PI was able to begin clinical training, which was originally planned to be done in her third/final year of the program. The board of radiology needs training for a physicist for three years before she can be eligible for board certification. By getting her clinical training during her entire post-doctoral training, she will be eligible to take her written and oral board radiology exams in diagnostic medical physics. At UW, she was also able to sit-in on medical physics classes to aid her qualification.

Body:

The tasks for the first year were performed at the University of Wisconsin, Medical Physics/Radiology department.

Since polycapillary optics cannot currently be made large enough for clinical application, the most practical method to produce larger optics is to couple several smaller tapered monolithic optics together to form one large optical array. One array was made of three tapers, which form a triad.[1,2] An extension of this triad is now a fourteen-tapered optic array.[3] This optical array was used for the first stage of this project.

Task 1. Investigate tapered monolithic optic performance, Month 1-12

a) Transmission as a function of energy

i) Individual Tapers
The x-ray source was a Senographe 500T mammography system. This is a three phase, 6 pulse generator with a molybdenum target tube. The focal spot was measured to be 0.31 mm ± 0.05 mm with a 10 μm slit. The voltage was set at 28 kVp so that most of the energy was in two characteristic lines, K_α at 17.5 keV and K_β at 19.6 keV, with a tube load of 12 mAs for each transmission image.

The detector was a digital Shad-o-Box X-ray Camera, which has a two-dimensional photodiode array containing 512 by 1024 48-μm pixels. An integral phosphor screen shields the sensor from ambient light and converts incident x-rays to visible light that is sensed by the silicon photodiodes. The dynamic range was measured with an ionic chamber connected to an electronic meter. The signal intensity plotted as a function of exposure shows a linear behavior of the dynamic range in figure 1.

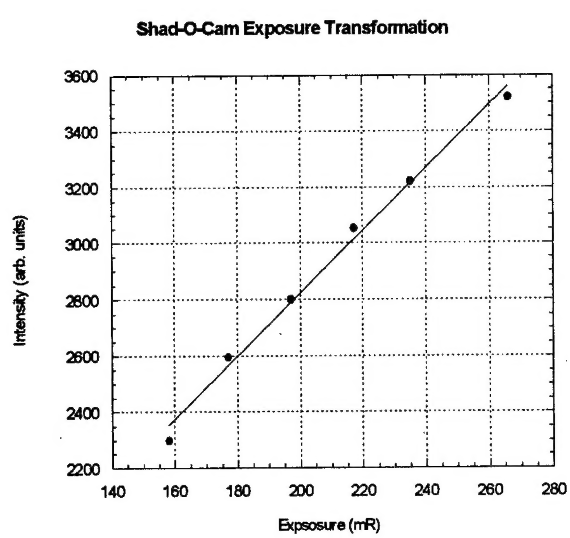

Figure 1. The linear behavior of the dynamic range of the shad-o-cam digital detector.

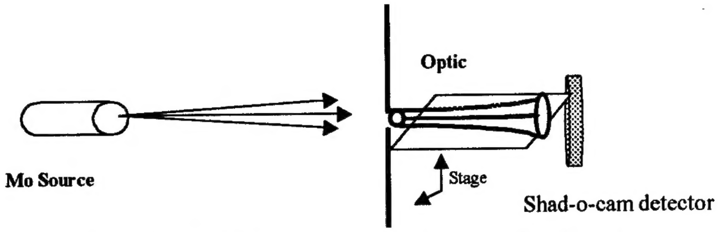

Figure 2. Experimental set-up for transmission and uniformity measurements.

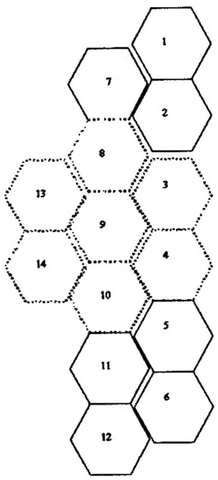

Figure 3. The number corresponds to table 1.

The transmission set-up is shown in figure 2. The transmission was measured by irradiating the x-ray camera simultaneously with radiation passing through the aligned optics and radiation bypassing the optic. The primary transmission factor is calculated by converting the pixel intensities in the image to exposure and using the ratio of the average exposure values in the two regions with background subtracted. Because of the linear dynamic range of the detector, the ratio of background subtracted signal intensities represents the fraction of the primary photons transmitted through the optic.

The optical array was positioned to maximize the transmission of one taper at a time and measured its transmission. The transmission of each taper is shown in table 1, with the taper number corresponding to the map of figure 3.

Some of the transmission values are quite high; this might be due to saturation of the pixel value without the optic. The pixel value was beyond 3600, which is beyond the linear part of the plot shown in figure 1. The average transmission of the individual tapers is 0.73 ± 0.16.

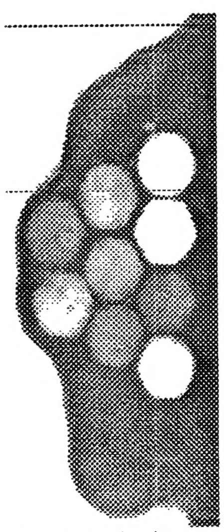

Figure 4. An image of the x rays passing through the optical array.

ii) Optical Array

A transmission image of the whole array of fourteen optics is shown in figure 4. This image was taken with source positioned to maximized the transmission in the seven adjacent tapers shown as dotted lines in figure 3. It is clear from the image that all of the tapers in the array are not pointed together to the source. The transmission of the array is 0.46 ± 0.30. This is a lot less than each individual taper transmission.

b) Transmission uniformity

The uniformity of the transmission within a single taper was measured by taking the intensity through 20 regions in the taper in the image with the transmission of the individual taper maximized. The relative variance is calculated by taking the standard deviation of the values from each area in the taper and dividing it by the mean value of that taper. The expected relative variance is calculated from Poisson

statistics, which is square root of the mean divided by the mean. The actual variance minus the expected variance is the non-uniformity, which is shown in the last column in table 1. For some tapers, the Poisson statistic is higher than the standard deviation divided by the mean, then the non-uniformity is negative.

Taper	Transmission	Non-Uniformity
1	0.62 ± 0.08	0.03
2	0.84 ± 0.07	0.01
3	0.82 ± 0.09	0.04
4	0.61 ± 0.09	0.06
5	0.67 ± 0.09	0.05
6	0.04 ± 0.01	-0.07
7	0.64 ± 0.12	0.10
8	0.57 ± 0.05	0.01
9	0.89 ± 0.03	-0.04
10	0.90 ± 0.04	-0.02
11	0.91 ± 0.04	-0.03
12	0.79 ± 0.16	0.12
13	0.77 ± 0.08	0.03
14	0.88 ± 0.03	-0.03

Table 1: Transmission and Uniformity of Individual Tapered Optics.

c) Magnification factor

Each tapered optic in the array has an input diameter of 2.5 mm and an output diameter of 4 mm. The magnification factor from the optic is 4/2.5 mm, or 1.6. This was verified by placing a washer of known diameter and measured the washer's diameter in the image. The diameter of the washer is 5 mm and on the image the diameter is measured to be 7.84 mm. This gives a magnification of about 1.6.

d) Magnification uniformity

Its uniformity was verified by taking three images of the washer and measured the magnification factor. The percentage error from the nominal value of 1.6 is only 2.1 % in these three images.

Task II: Clinical Training Month 1-12

Clinical training was pursued by taking courses and working with the quality assurance group at the University of Wisconsin hospitals and clinics. Since the grant does not pay for tuition for classes, the PI audited/sat-in in the required courses, which every graduate student in medical physics program has to take. The PI fully participated in these courses, which means that she did all the homework, labs and lab write-ups and took all the exams.

Summer 2002:
Medical Physics 662: Diagnostic Radiology Physics laboratory.

It includes quality assurance of one radiographic, one fluoroscopic, and one mammography unit.

Fall 2002:
Medical Physics 567: The Physics of Diagnostic Radiology.
This course is about the physics of x-ray diagnostic procedures and equipment, radiation safety, and general imaging considerations. This course also offers a laboratory, which includes x-ray production of the radiographic system, measurement of HVL, kVp, and exposure time, attenuation measurements and beam hardening, film and screen-film characteristic curves, anti-scatter grid alignment and artifacts, focal spot measurements, and fluoroscopy.

Medical Physics 501: Radiological Physics and Dosimetry.
Interactions and energy deposition by ionizing radiation in matter, concepts, quantities and units in radiological physics; principles and methods of radiation dosimetry.

Spring 2003:
Medical Physics 566: Physics of Radiotherapy.
Ionizing radiation use in radiation therapy to cause controlled biological effects in cancer patients. Physics of the interaction of the various radiation modalities with body-equivalent materials and physical aspects of clinical applications. This course also offers a laboratory, which includes introduction of radiation oncology and dosimetry systems, radiation oncology physics – quality assurance principles, photon beam output dependency, field flatness, symmetry and timer error of cobalt-60 unit, photon output measurement techniques, electron output measurement techniques, treatment planning.

The quality assurance group at University of Wisconsin hospital and clinics (June 2002-June 2003)

The quality assurance group consists of 2 graduate students, 1 Ph.D. candidate, the PI, and 2 advisors. They work on the average of 20 hours/week. Their job is to do the following:
- assist in the selection and purchase of new medical imaging equipment and the upgrading of existing units, including all types of x-ray imaging systems, and personal radiation protection items.
- perform the acceptance testing of all new clinical x-ray imaging equipment, including CT, fluoroscopic, and radiographic machines, AND federal government's MQSA program for mammography.
- test all newly acquired personal radiation protection items for proper construction and for sufficient radiation attenuation.
- perform weekly testing of three nuclear medicine systems.
- perform shielding calculations and surveys, including shielding design for new or modified installations, and assist in room design and planning.
- consult with clinicians to determine the radiation exposure patients receive from medical imaging examinations or the exposures received by the fetuses of pregnant patients.
- perform testing of malfunctioning medical imaging equipment to determine the causes of any problems and suggest a proper course of action to the service personnel and the clinical staff.

• provide instruction to the radiology residents and radiological technology students in: the physics of medical imaging, including the operation of all types of imaging equipment and the best use of this equipment – image quality & radiation safety.

The units are in UW hospitals and clinics, Meriter hospital, and UW Vet school. UW has 41 radiographic, 35 fluoroscopic, 3 dental, 6 computer tomography, and 6 mammography units, which needs to be tested annually and semi-annually. Meriter hospital has 18 radiographic, 5 fluoroscopic, 2 computer tomograhy, and 6 dental, and 1 mammography units which needs to be tested annually. The PI has also participated in testing one mammography unit in Beloit which is located outside of Madison.

The PI is fully involved in testing radiographic, fluoroscopic, and dental units. Testing radiographic units involves visual and manual inspection, light field/x-ray congruence, artifact test, grid alignment, focal spot size, x-ray exposure output, tube filtration/beam quality/HVL, overall image resolution, kVp station accuracy, kVp reproducibility, and AEC tests.

Testing fluoroscopic units includes visual and manual inspection, TV image/x-ray field congruence, fluoro image distortion, focal spot size, x-ray exposure output/HVL, fluoro kVp station accuracy, fluoro high contrast resolution, fluoro maximum exposure rate, fluoro low contrast detectability.

Testing dental units include focal spot size measurement, x-ray exposure output/HVL, and fluoro kVp station accuracy.

According to the American College of Radiology, one needs an initial training of 20 contact hours of training in conducting surveys of mammography facilities, and experience in conducting mammography surveys of at least 10 units and at least one facility, AND at least eight hours of training with a specified modality e.g. digital. Initial experience includes one facility and 10 units and then continuing experience of 2 facilities and 24 units in 24 months.

The PI tested two units in Beloit for 8 hours and UW for 5 hours. Instructions in conducting surveys lasted 5 hours. The testing includes assembly evaluation, collimation assessment, evaluation of focal spot performance, AEC system performance, uniformity screen speed, artifact evaluation, phantom image quality evaluation, kVp accuracy and reproducibility, beam quality assessment, breast entrance exposure, average glandular dose and radiation output rate, and view box luminance and room illuminance. These tests can meet the initial qualification for board certification in mammography.

Key Research Accomplishments:

• The transmission of the optic is 0.73 ± 0.16 if all the tapers were pointing to the source over the range of 17.5 keV and 19.5 keV.

• The uniformity of the optic is quite good.

• The magnification factor is 1.6, which coincides with the geometrical ratio of the tapered input and output diameters.

• The error in magnification uniformity is only 2.1 %.

• The PI got a head start in clinical training. She has accomplished one year of clinic training for diagnostic radiology.

• She also accomplished 18 hours of 2 mammography units quality assurance.

Reportable Outcomes:

• The PI attended of Era of Hope conference in Orlando, FL in September 2002. She learned the state of art research in breast cancer in other institutions.

• The PI received employment opportunity from Eastman Kodak Health Imaging Laboratory based on both the medical physics classes/clinical training and her research experience supported by this award.

Conclusions:

Although the optical array does not give a good transmission (max. 46 %) because of misalignment of the tapers, it can be used for testing resolution and contrast, which are the topics for the next stage. The magnification agrees with the designed magnification of the tapers. By allowing the PI to start her clinical training in her first year, she can be eligible of board certification when she ends her postdoctoral training.

Reference:

[1] C. D. Bradford, "Multi-tapered X-Ray Capillary Optics for Mammography." Ph.D. thesis, University of Wisconsin – Madison, 2000

[2] C. D. Bradford, "Multi-tapered X-Ray Capillary Optics for Mammography. Medical Physics 29 (6), June 2002

[3] R. E. Ross, "Optimization of X-Ray Capillary Optics for Mammography. SPIE 4682: Physics of Medical Imaging, 2002.